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MULTI DECADAL ASSESSMENT OF LULC DYNAMICS OF A RAMSAR WETLAND IN HARYANA USING REMOTE SENSING AND GIS TECHNIQUES (2001–2024)

Abstract: Wetlands are one of the most productive ecosystems of the world, serving various benefits to local flora and fauna as well as anthropogenic activities such as tourism, fisheries and so on. They offer various natural, social, and economic activities. Wetlands around the world are suffering degradation because of various human activities around them. One such wetland in this context is Bhindawas wetland in Haryana state of India. A multi decadal comprehensive analysis of its Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI) was done with the help of remote sensing and GIS techniques. Google earth engine facilitated the analysis with the help of its in-house availability of various satellite datasets. For this purpose, Landsat 5 TM for the year 2001 and Landsat 8 OLI/TIRS for the years of 2014 and 2024 were utilized. QGIS 3.34 helped in map making. Random Forest Classifier, was used for preparing LULC maps. LULC analysis highlights the fact that builtup area has increased at an alarming rate, but vegetation and aquatic vegetation have taken a significant toll. Overall accuracy of the LULC classification for 2001, 2014, and 2024 is 0.94, 0.92 and 0.90 and kappa coefficient is 0.92, 0.88 and 0.87 respectively. NDVI and NDWI have also undergone significant transformation with decline in vegetation and drier than ever conditions in and around the wetland. The research provides a solid base to be carried forward in the future studies of the wetlands and will help in eco-friendly policies.

Keywords: buffer analysis, builtup, Google Earth Engine, remote sensing; wetlands

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Introduction with analysis of the state of the problems

Wetlands are the areas where soil is covered by water, water could be present at or beneath the soil surface (USEPA, 2025). Wetlands are one of the most productive and valuable ecosystems in the world and they are an important habitat providing natural, economic, and social services to the local community (Mitsch & Gosselink, 1993; Mitsch & Gosselink, 2000; Mitsch & Gosselink; 2015). In the current world scenario, wetlands hold more prominence than ever because of their ability to support fisheries, recreation, and tourism sectors, generating billions of dollars around the world annually (Millennium Ecosystem Assessment, 2005; Hu et al., 2017). In the contemporary world, wetlands around the world are undergoing degradation in terms of quality and quantity (Davidson, 2014; Kaur & Singh, 2025). According to Davison (2014) since the beginning of the 20 the century as much as seventy percent of the wetlands might have already been lost, inland wetlands have suffered more environmental degradation as compared to their coastal counterparts, developing countries, particularly in Asia, the loss of wetlands is much higher as compared to Europe and North America. In the context of India, according to Prasad et al (2002) earlier wetlands covered about 58 million square hectares, with variety of wetlands from high altitude wetlands to dry, hot and humid wetlands near coastal regions but now they only cover about 15.26 million square hectares (Ahmad et al., 2024). From conservation's point of view, it is important to preserve and protect the wetland ecosystem. There are variety of way to solve the problems surrounding wetland degradation, but one such idea is to apply remote sensing and GIS techniques, as it provides firsthand information about the study area and nowadays there are multiple methodologies and indices we can apply for detailed analysis (Ozesmi & Bauer; 2002; Guo et al., 2017; Mahdavi et al., 2017). Doing a buffer analysis is one such technique where we study not only the wetlands but also their surrounding environment, few studies have in the context of wetlands have demonstrated this (Xu et al., 2022; Singh et al., 2024; Verma et al., 2024; Kaur & Singh, 2025). In recent years, there has been rapid builtup expansion, agricultural intensification, climatic changes with erratic rainfall patterns and warming temperature trends across the globe have significantly altered the physiology and hydrology of the wetlands. The advancements in the remote sensing, GIS and cloud-based computing services have enabled the processing of large datasets easy and effective. Google earth engine is such platform which enables the processing of high-quality datasets that are readily available to use and perform analysis on. Analysis of Land Use Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Builtup Index (NDBI) and Land Surface Temperature (LST) has been made much easier to perform giving an in-depth context of spatial and temporal changes.

In this current context of this research, it aims to study the wetland ecological status with the help of latest remote sensing techniques by not only analysing the wetland's area but also the spatial transformation of land use that is happening around it. It aims to understand the ecological health and long-term sustainability of the wetland, which in turn can serves as a benchmark for wetland conservation.

Materials and methods

Research methodology involves acquisition of data, preparation of multi decadal LULC maps, analysis of indices using Normalized Difference Water Index (NDWI) and Normalized Difference Vegetation Index (NDVI). To better understand the LULC dynamics a buffer of five kilometers has been applied, as it has been demonstrated by many studies (Kaur & Singh, 2025; Verma et al., 2024). Buffer analysis helps in understanding the LULC dynamics around the protected area which can lead to effective implementation of conservation strategies. Preparation of LULC maps, NDVI and NDWI was done on google earth engine which allows for large scale spatial data analytics without the need of storing it in the personal device (Gorelick et al., 2017). Final preparation of maps was done on QGIS 3.34.

For preparing the LULC maps, supervised classification was performed. LULC maps for the year 2001, 2014 and 2024 were prepared. For preparation of LULC maps satellite imageries of Landsat were acquired from google earth engine's data catalogue. For LULC analysis of the year 2001 Landsat 5 Thematic Mapper (TM) was utilized and for 2014 and 2014 Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) was utilized. Pre-processing steps involved selecting the dates, cloud cover filter, and creating a median image from collection of images. For LULC classification, Random Forest Classifier which is a machine learning technique was used, it was chosen because of its higher accuracy of classification and its better handing of data (Rodriguez-Galiano et al., 2011; Rwanga & Ndambuki, 2017; Amini et al., 2022; Junaid et al., 2023). Accuracy assessment and Kappa coefficient were also calculated after doing LULC classification.

For preparation of NDVI and NDWI, required bands were utilized to extract these indices. Equation 1 and 2 mentions the method of extracting NDVI and NDWI, respectively.

$$NDVI=\frac{(NIR-RED)}{(NIR+RED)} \quad (1)$$

$$NDWI=\frac{(GREEN-NIR)}{(GREEN+NIR)} \quad (2)$$

Based on this, a comprehensive analysis of wetland as well its proximate environment was performed as to analyze how much change has happened during the considered period this research.

Study area. Bhindawas wildlife sanctuary or wetland is the largest wetland in the state of Haryana. It is man-made freshwater wetland falling under the administrative region of Rohtak, Haryana. It was declared as a protected area in the year 1986 by Ministry of Environment, Forest, and Climate Change (MoEFCC) and in 2011 it was designated as Eco-sensitive zone to better protect the wetland and its peripheral environs. Wetland is situated at 28°32'01" N to 76°33'01" E. Wetland is a significant from environmental perspective as it houses various floral and faunal species. Hundreds of migratory avian species gather at the wetland, which serves as roosting and resting site. As mentioned earlier, it is the largest wetland in all of Haryana having a periphery of 12 kms and water depth of around 6 feet (Shan et al., 2021). Jawahar Lal Nehru Canal supplies the water into the wetland. Figure 1 illustrates the location of the study area.

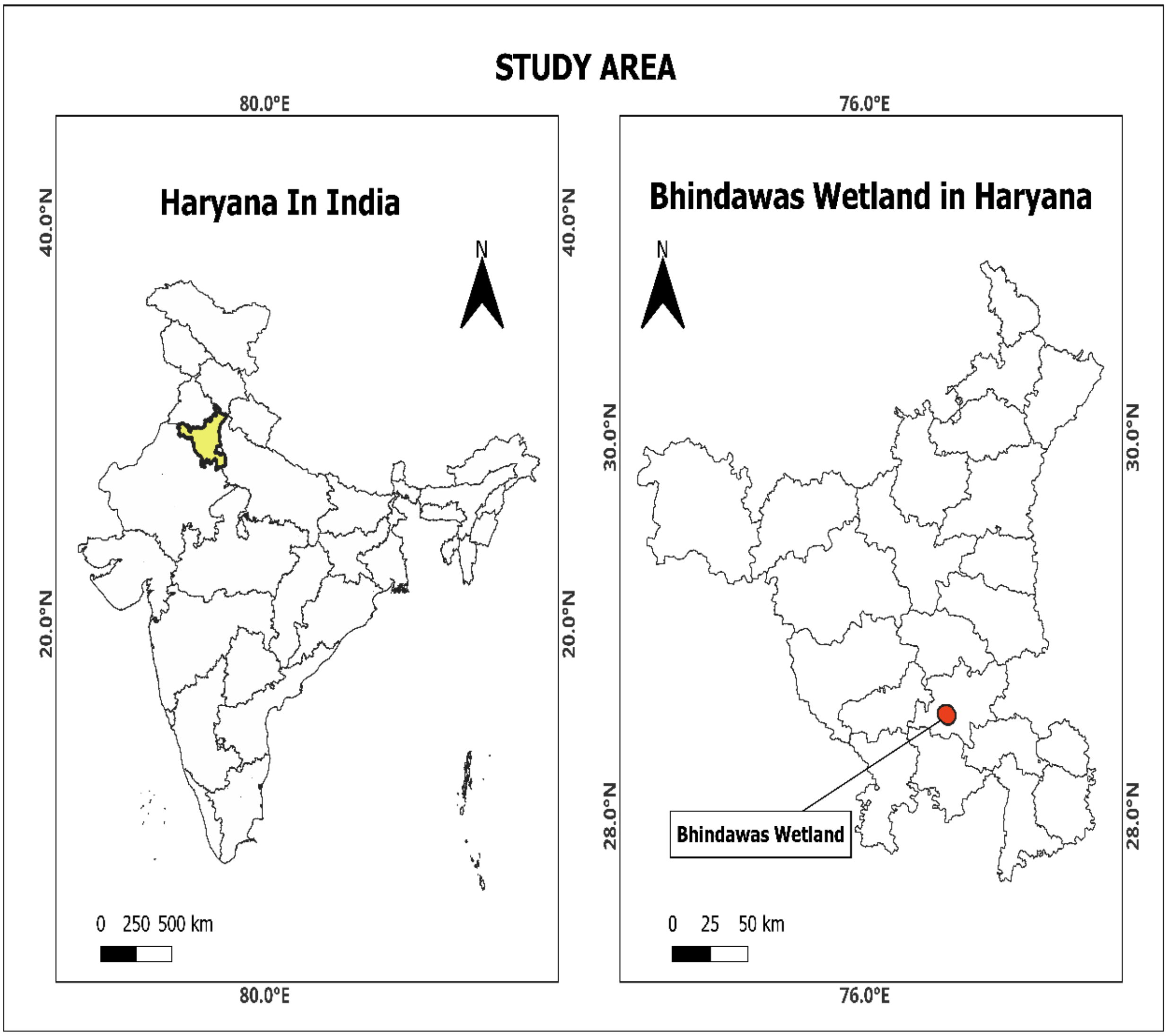

Fig. 1. Study area of Bhindawas wetland, Haryana
Source: own elaboration in QGIS 3.34

Results

The results have been divided into the following parts, these are (i) Analysis of LULC dynamics of the Bhindawas wetland (ii) Accuracy Assessment of the LULC classification (iii) NDVI analysis (iv) NDWI analysis.

LULC dynamics of Bhindawas wetland. For the LULC classification, years of 2001, 2014 and 2024 was done on google earth engine. Based on that the analysis five LULC classes were identified, these are Builtup, Waterbody, Aquatic Vegetation, Vegetation, Agriculture, Barren land. Various combinations of Landsat bands helped in the identification of these LULC classes. Some important highlights based on our analysis are in Figure 2.

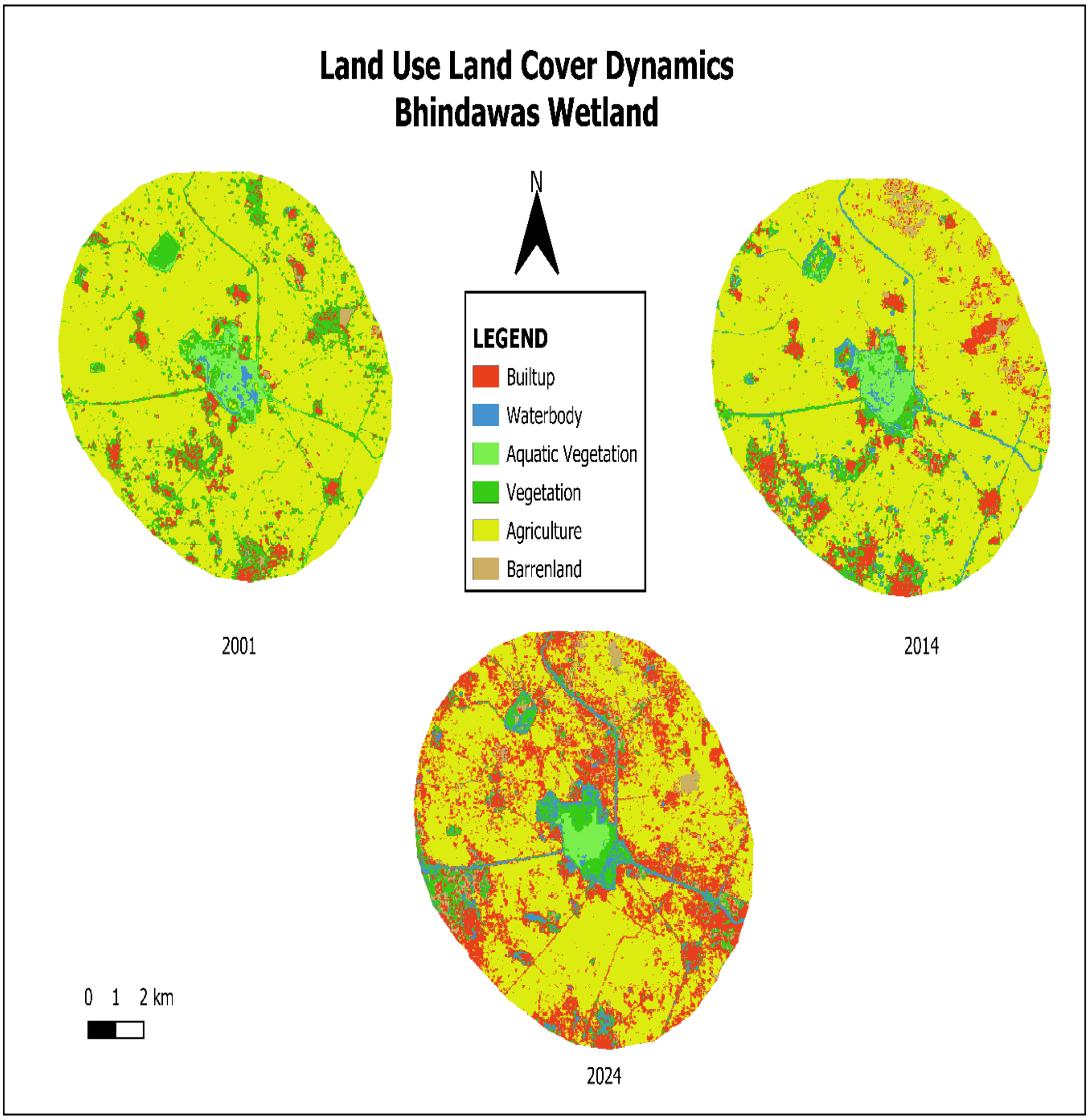

Fig. 2. Graphical presentation of LULC analysis of Bhindawas wetland, Haryana (2001, 2014, 2024)
Source: own elaboration in Google Earth Engine, visualized in QGIS 3.34

There has been significant increase in the urban footprint, in 2001 only 5.82 sq. kilometers was covered by the builtup area, while in 2014, it increased to 15.86 sq. kilometers, however coming to 2024 builtup coverage expanded to 28.59 sq. kilometers, in these twenty-four years builtup area has increased by 391%, which can be considered exponential expansion, now covering almost thirty-three percent of the study area. Areas around the wetland's proximity such as Bhindawas, Khetawas, Mundahera. Redhuwas, Niwada, Nawada and so on have seen significant growth of urban footprint. Waterbodies on the other hand have seen a steady increase, though this increase does not appear to be in consonance with the quality of wetland. Rather it has to do with increase in the canal network, artificial ponds and water tanks, waterbodies in 2001 were 0.67 sq. kilometers, in 2014 it was 4.19, waterbody content was maximum in 2014, when there were many artificial sources of water popping up in the study area, but coming to 2024, it has declined to 2.87 sq. kilometers, though there is an increase overall in the quantity of waterbodies in the study area from 2001 to 2024, and the increase is 328 %. Figure 2 gives a graphical illustration of the LULC analysis. Table 1 gives us an insight into the LULC dynamics of the study area.

Table 1. Class wise LULC Analysis of Bhindawas wetland from 2001 to 2024

Class	2001	2014	2024	Net change in sq. kilometers (2001 to 2024)	Percentage change (2001 to 2024)
Builtup	5.82	15.86	28.59	22.77	391%
Waterbody	0.67	4.19	2.87	2.2	328%
Aquatic Vegetation	2.83	2.23	1.57	-1.26	-44.5%
Vegetation	15.31	9.86	7. 23	-8.08	-53%
Agriculture	80.13	68.08	61.09	-19.04	-24%
Barren land	0.53	5.07	3.94	3.41	643%
Total	105.29	105.29	105.29		

Source: own elaboration based on Google Earth Engine

Aquatic vegetation on the other hand has been on constant decline. Aquatic vegetation is a vegetation partially or fully submerged in an aquatic ecosystem, and this vegetation serves as food to aquatic animals, therefore can be considered important to the health wetland, estuaries (USEPA, 2006). Area covered by aquatic vegetation in 2001 was 2.83 sq. kilometers, in 2014 it was 2.23 sq. kilometers, coming to 2024, aquatic vegetation has reduced to 1.57 sq. kilometers, a decline of 44.5 percent. Another important LULC class to have taken a similar decline in terms of areal extent is vegetation, in 2001 it covered an area of 15.31 square kilometers, in 2014 it had gone down to 9.86 sq. kilometers, the latest analysis of the vegetation reveals that now it stands at 7.23 sq. kilometers, much of this decline can be attributed majorly to increase in the builtup areas along with fluctuations in other LULC classes. Overall decline of vegetation from 2001 to 2024 stands at negative 52.8 percent. Agriculture is another class which has registered decline in its area, areal coverage of agriculture stood at

80.13 sq. kilometers in 2001, it decreased to 68.08 sq. kilometers in 2014, then in 2024, it declined further to 61.09 sq. kilometers.

Agricultural area decreased by nearly 24 percent during this period. Barrenland has increased from 0.53 sq.kms in 2001 to 5.07 sq. kms in 2014, and in 2024 it covers 3.94 sq. kilometers, though from 2001 to 2014, its area increased but from 2014 to 2024 it registered a decline, which could be attributed to the land use policies and practices of the study area.

Accuracy assessment and kappa coefficient. Accuracy assessment and kappa coefficient are considered important for evaluating how well the pixels were correctly classified (Ismail & Jusoff, 2008). For doing LULC classification and thereafter evaluating its accuracy many studies have employed these metrics of overall accuracy calculation and kappa coefficient (Dihkan et al., 2013; Rwanga and Ndambuki, 2017; Nguyen et al., 2018; Abbas & Jaber, 2020). Based on that overall accuracy and kappa coefficient are provided in the Table 2, all the values given can be considered reliable and good for future land use planning of the study area.

Table 2. Overall accuracy and kappa coefficient

Metric	2001	2014	2024
Overall Accuracy	0.94	0.92	0.90
Kappa Coefficient	0.92	0.88	0.87

Source: own elaboration based on Google Earth Engine

NDVI analysis of Bhindawas wetland. NDVI is a popular technique for evaluating the status of vegetation, its actual purpose it to enhance the quality of vegetation analysis with the remote sensing data (Huang et al., 2021). Many studies have deployed NDVI particularly in the wetland areas to study the dynamics of vegetation happening in and around the wetland (Ashok et al., 2021; Verma et al., 2024; Kaur and Singh, 2025). Based on that an appropriate analysis of vegetation changes has been done with the help of NDVI (Figure 3). The analysis highlights a clear trend of vegetation degradation over the period of twenty-four years. In the year of 2001, the minimum and maximum values range from 0.008 to 0.43 indicating presence of healthy vegetation in and around the wetland area.

In 2024, the minimum and maximum values range from 0.002 to 0.39, indicating sharp decline in vegetation cover and health in the next decade, with increase in builtup areas, changes in the other LULC areas. But in 2014, the minimum and maximum values are 0.005 and 0.42, respectively. Indicating decline in the vegetation cover, not that much in the vicinity of the wetland, rather in areas that are far away from the wetland, which can be attributed to the increase in the builtup areas and land cover changes. The overall change in the vegetation status is negative although.

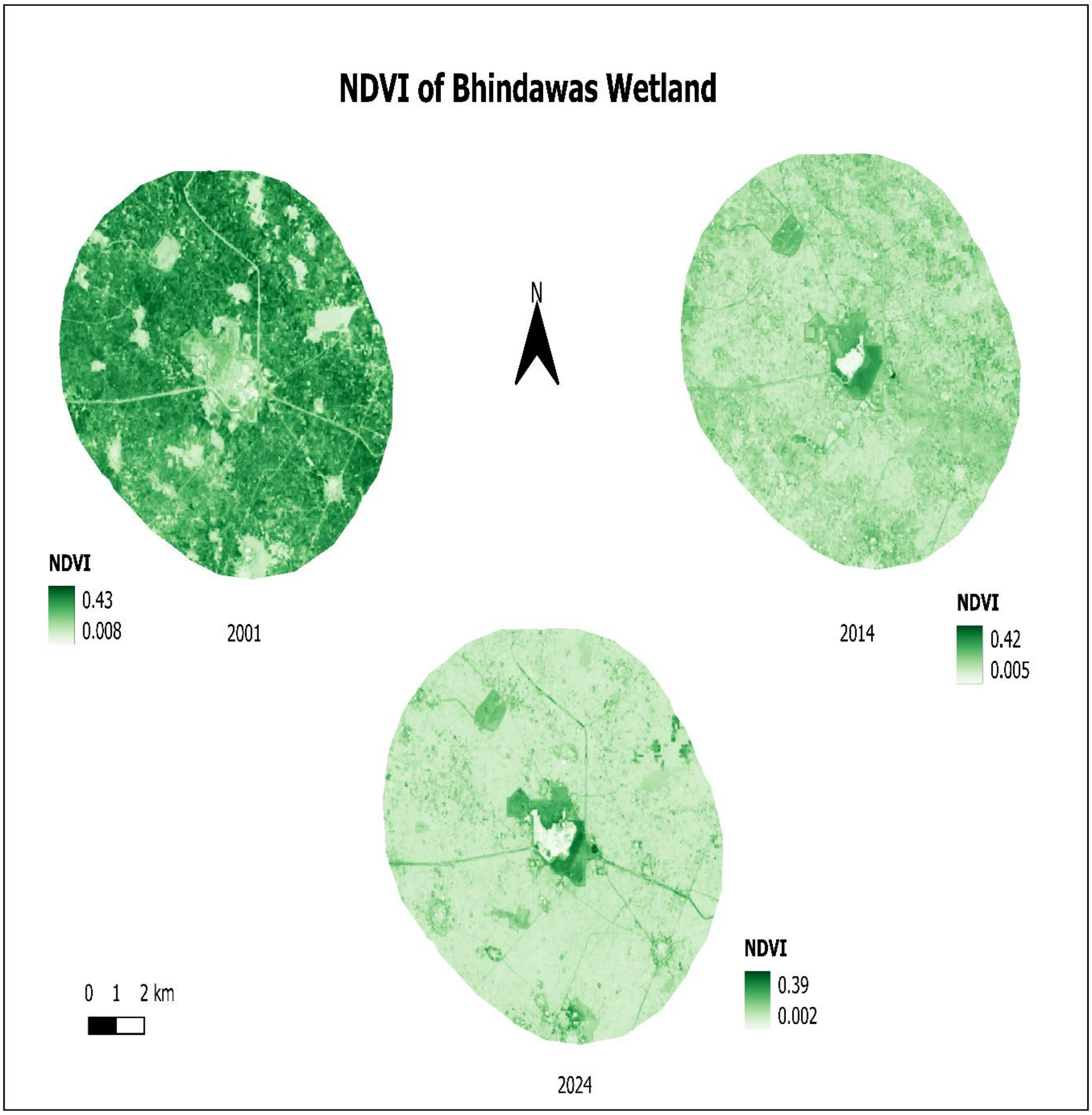

Fig. 3. NDVI of Bhindawas wetland, Haryana (2001, 2014, 2014)
Source: own elaboration in Google Earth Engine, visualized in QGIS 3.34

NDWI analysis of Bhindawas wetland. Along with NDVI, the analysis of NDWI has been done to better understand the water and moisture dynamics in and around the wetland.

The NDWI trend of the wetland and its environs for the years of 2001, 2014 and 2024 shows subtle but consistent decline of water and moisture conditions. In our analysis of 2001 year, there appears to be values closer to zero which suggests moderate wetness around the wetland and its core areas. Negative values are indicative of non-water surface features, which indicates presence of concrete surface and dry vegetation. In the later years, there appears to be signs of degrading moisture and water content in the study areas, With shrinkage of wet zones and its subsequent fragmentation.

The overall analysis reveals more drier conditions than ever in 2024 as compared to 2001, which can be attributed to increase in the anthropogenic conditions in the form of builtup areas, encroachment, and decrease in hydrologic inflow (Figure 4).

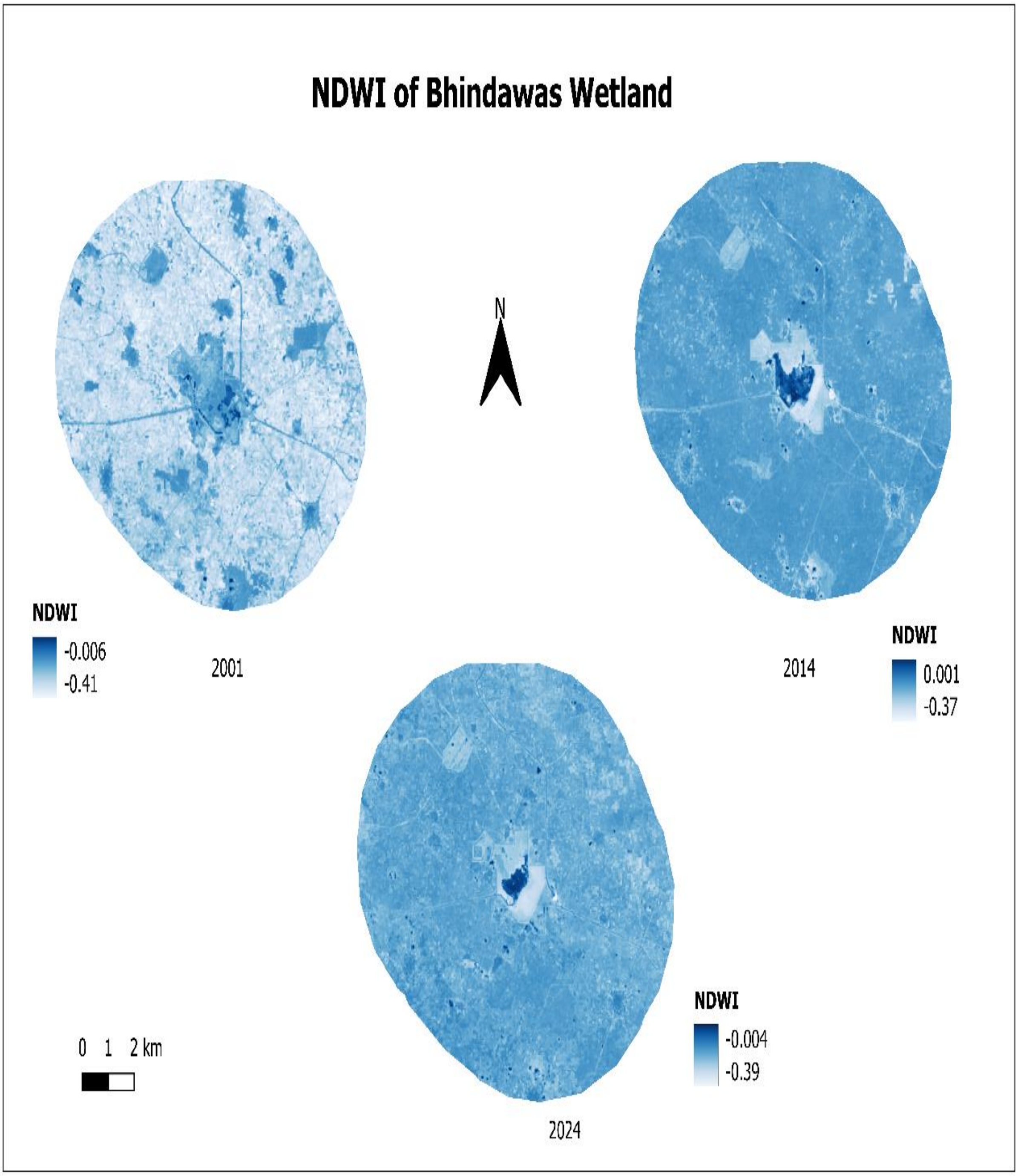

Fig. 4. NDWI of Bhindawas wetland, Haryana (2001, 2014, 2014)
Source: own elaboration in Google Earth Engine, visualized in QGIS 3.34

Discussion

Builtup area has increased in the surrounding environments of the wetland, there has been a fourfold increase in the builtup areas, such changes have been a matter of concern for policymakers and environmentalists alike (Mondal et al., 2017). Agriculture was once a dominant category twenty-years back, covering more than eighty percent of the study area, even though it still is the largest LULC category but its areal influence is certainly decreasing and now appears to be getting replaced in favor of builtup area. Special attention is to be given to those areas which had sparse or segregated vegetation. The negative NDVI trend over twenty-four years highlights the fact that there has been progressive decline of vegetation within and the vicinity of the wetland. This trend warrants the need for strategic planning for conservation of vegetation, effective land use land cover planning, better land management policies so that ecology of the wetland can be preserved. Ecological impacts have been observed on the wetland's environments with increase in anthropogenic dynamics being altered at the expense of wetland's ecology (Junk et al., 2013; Kaur & Singh, 2025). This is the same case concerning Bhindawas wetland and its environs. Based on the buffer analysis performed there has been a consistent trend of vegetation, water and moisture decline with dwindling vegetation as well as decline in aquatic vegetation that supports the overall functioning of the wetland's ecosystem. NDVI and NDWI indices show negative trend with increase in builtup areas and other changes in land use land cover dynamics. Other studies showing such trends also appear to be happening in the north Indian wetlands such as Hari-ke-Pattan of Punjab and Parvati Arga wetland of Uttar Pradesh.

Anthropogenic influences. Wetlands around the world are threatened by climatic and anthropogenic factors, with those situated in arid and semi-arid regions are affected the most (Khelifa et al., 2021). With anthropogenic activities, comes the problem of habitat destruction of species, pollution from agriculture and industries alike. Petrescu et al. (2015) in their study have highlighted how certain land use policies influenced by humans can exacerbate the local dynamics of carbon dioxide, methane, and other gases which in turn the degrade the quality of the wetlands, those situated in temperate regions. Since, this research reveals significant interference of humans in and around the wetland's proximity and this theme of dominant human interference appears to be in uniformity with other wetlands situated in India (Ahmad et al., 2024). Since, it would be not practical to completely stop human activities around wetlands and other natural ecosystems, it would be wise to regulate human activities in a manner that are less detrimental to the natural environment and go a long way towards realising a symbiotic relationship between humans and nature.

Ecological and biodiversity implications. Research shows that Bhindawas wetland is undergoing transformation of land cover with decreasing vegetation and aquatic vegetation, which are quintessential for proper functioning of wetlands, Vegetational content help in moisture circulation and maintenance of positive equilibrium of wetlands in the form of balancing of water nutrients, removal of pollutants and even heavy metals (Shan et al., 2021). Haritash et al. (2015) in their study of Bhindawas wetland's environmental status have found excess levels of nitrate (50.5 mg/l) and phosphate (4.9 mg/l) attributable the agricultural runoff. Because of agricultural runoff and other water solids from human activities it can cause the surface of the wetland suffer from salinity, weed accumulation, water logging which in turn can jeopardize the flora and faunal community of the wetlands (Kumar & Dhankar, 2015). In altered wetlands, that is those modified by humans can house abundant species of flora and fauna, but those species may not have the lifespan and habitat qualities that would be found in an unaltered wetland or natural environment (Sievers et al., 2018). Given the fact that, wetlands house various taxa within their environment is important to preserve their ecological sanctity with urgent need of conservation policies and framework.

Conclusions

As evidence suggests there appears to be a trend of increase in builtup areas the expense of vegetation, aquatic vegetation and even agriculture. Earlier agriculture used to dominate the landscape of Bhindawas wetland but now it reducing in size as builtup areas are increasing rapidly. The LULC analysis along with NDVI and NDWI analysis highlight a negative trend for wetland supporting services with decrease in vegetation and moisture conditions in and around the wetland.

To protect wetland of international importance it is important to work in a manner that is synergetic and involves various stakeholders from policy makers, scientists, town, and country planners as well as the local people, only then we can move forward to protects these special habitats and maintain harmony between humans and nature.

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Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Public Data: The data utilized is available in the public domain on the google earth engine platform.

Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were employed in the preparation of this manuscript.

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